application note

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LIMITATION OF DV/DT AT COMMUTATION WITH AN RC SNUBBER NET WORK

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When a triac is used to control an inductive load, the voltage can be reapplied with a high rate of change (dv/dt) after turn-off. If this dv/dt exceeds the critical rate of change of commutation voltage of the triac, it may cause an undesired non-gated turn-on of the triac.

To avoid this undesired turn-on and assure reliable operation, it is necessary to limit the dv/dt at the commutation. The simplest method is the use of an RC network across the main terminals of the triac (Fig.1).

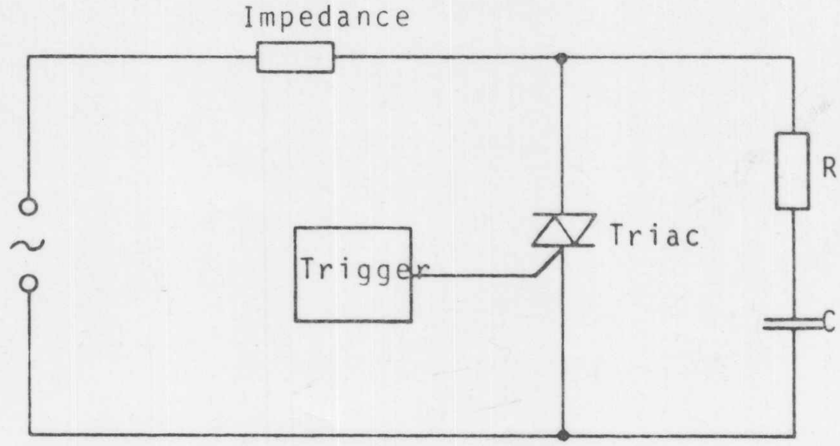


Fig. 1

The proper selection of the components of this snubber network is very important. Inadequate values can cause malfunctionning of the circuit and eventually damage some components.

Consider the case of a load with an impedance $Z = R + j\omega l$ (Fig.2).

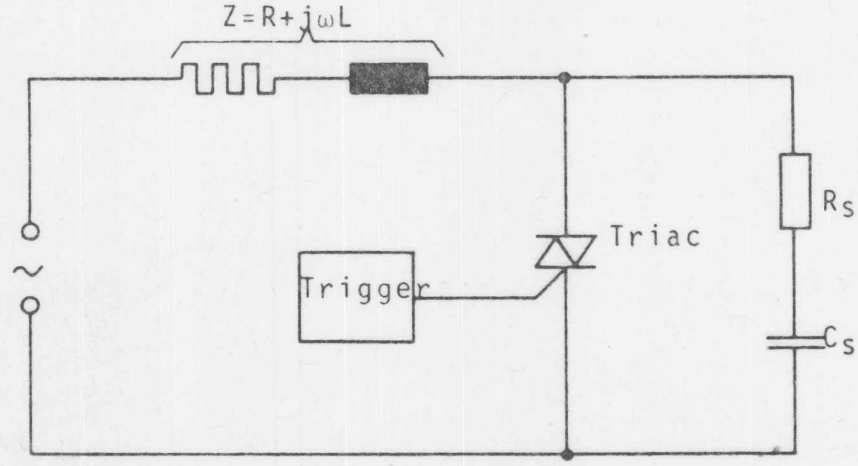


Fig.2

Fig. 3 shows the current and voltages at triac turn-off:

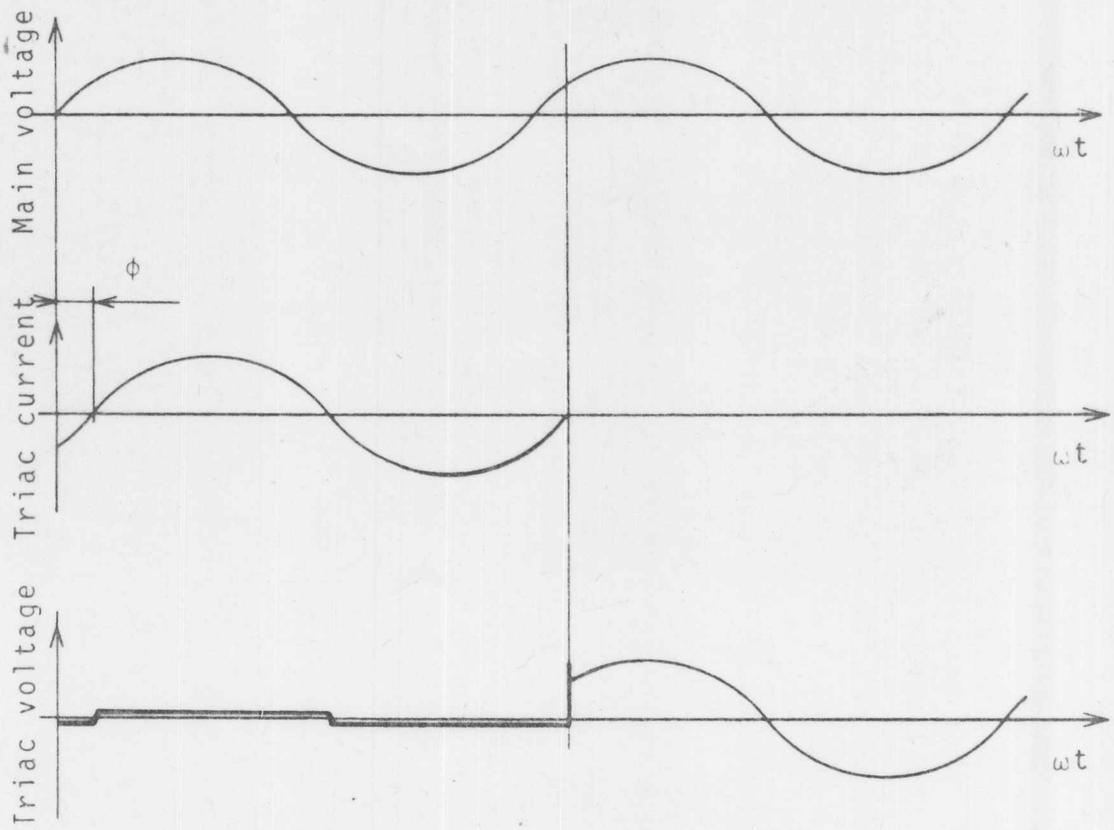


Fig. 3

The mains voltage is given by the equation

1) $$u_{(t)} = U_M \sin \omega t$$

When the triac is turned-on, the current is lagging the voltage by an angle ϕ :

2) $$i_{(t)} = I_M \sin (\omega t - \phi)$$

3) $$I_M = \frac{U_M}{Z}$$

4) $$Z = \sqrt{R^2 + \omega^2 L^2}$$

5) $$\phi = \tan^{-1} \frac{\omega L}{R}$$

The triac turns-off at time t_o (Fig.3) when $\omega t_o = \phi$.
Current and voltage are :

6) $$U_{(to)} = U_M \sin\phi$$

7) $$I_{(to)} = I_M \sin 0 = 0$$

Fig.4 gives the vectorial representation at time to :

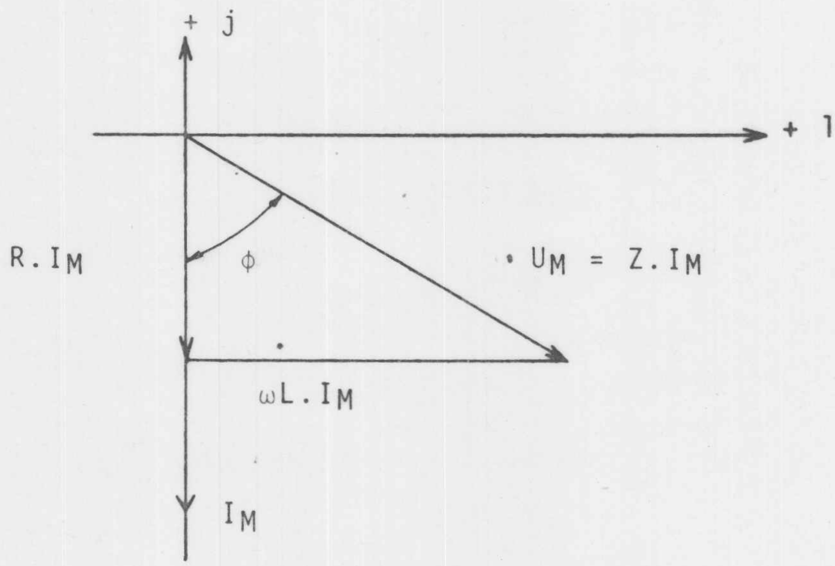


Fig.4

When the triac has turned-off, the circuit impedance becomes :

8) $$Z' = R + j\omega L + R_S - \frac{j}{\omega C_S}$$

Fig.5 shows the voltages after turn-off :

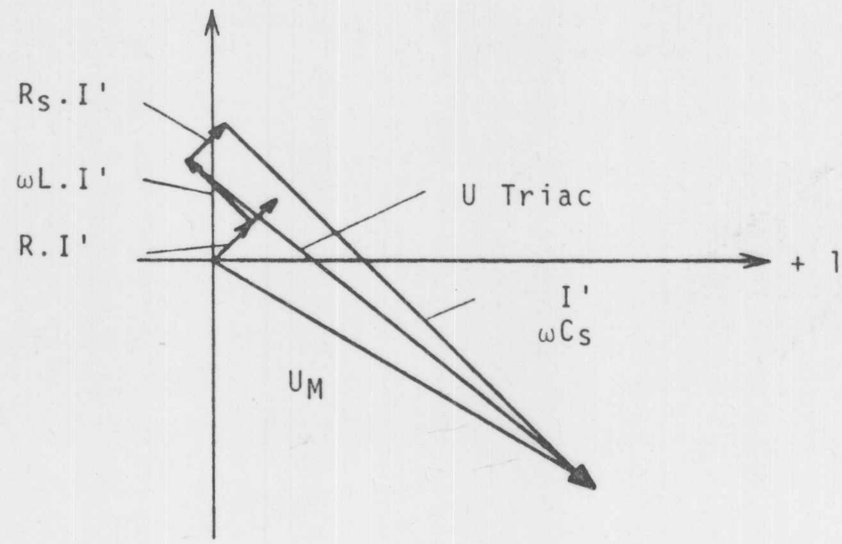


Fig. 5

The voltage applied to the main terminals of the triac is :

9) $$U_S = I' . Z_S$$

10) $$Z_S = \sqrt{R_S^2 + \frac{1}{\omega^2 C_S^2}}$$

11) $$I' = \frac{U_M}{Z'}$$

When the triac turns-off at time t_0, the circuit goes from the situation shown in Fig.4 to that of Fig.5 with a speed ω_0 given by the equation :

12) $$\omega_0 = \frac{1}{\sqrt{L . C_S}}$$

The voltage on the triac at turn-off is shown by figures 6a and 6b. The amplitude of the oscillation depends on the coefficient of quality Q of the oscillating circuit :

13) $$Q = \frac{\sqrt{\frac{L}{C_S}}}{R + R_S}$$

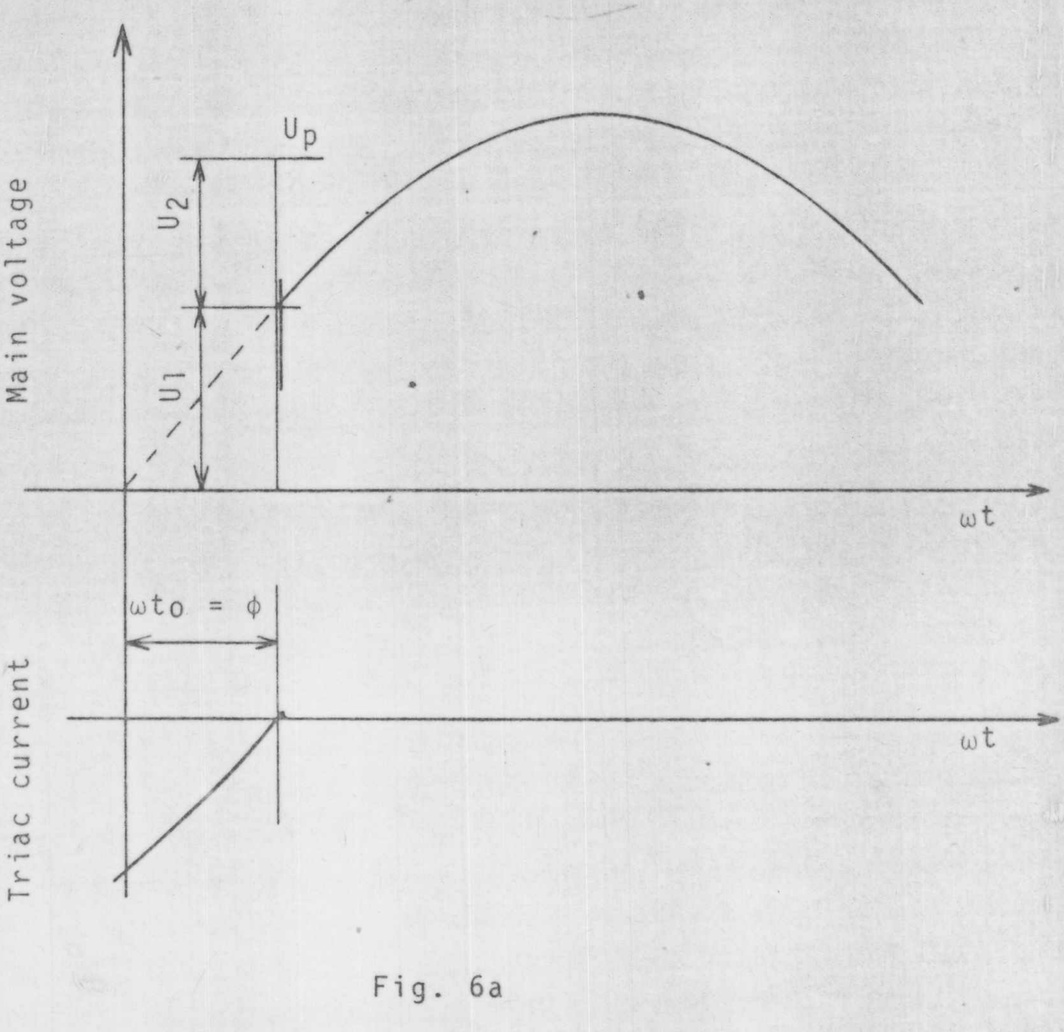
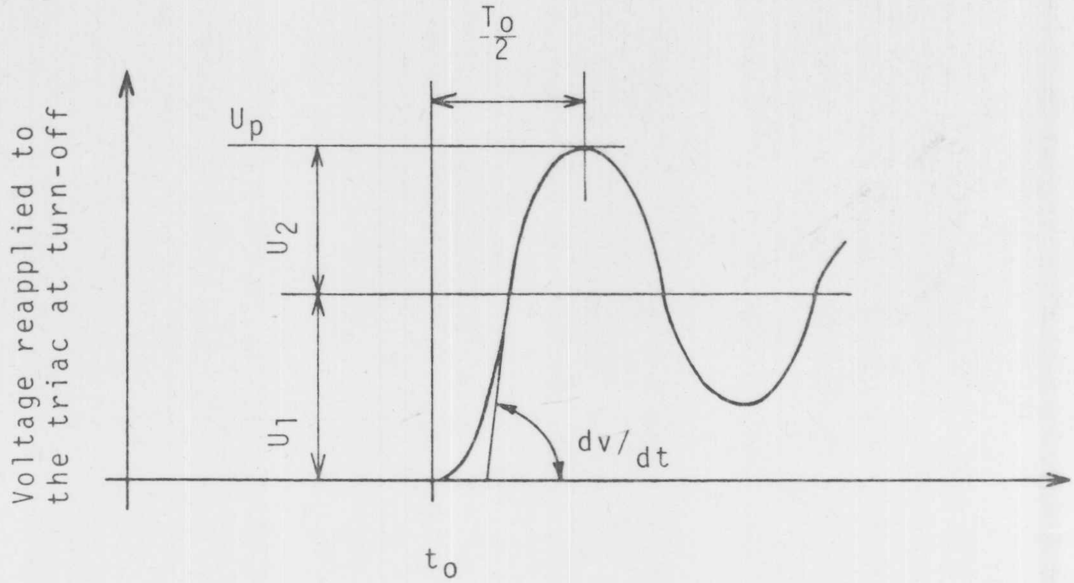


Fig. 6a



In practice, $R + j\omega L << R_S - \dfrac{j}{\omega C_S}$.

We can assume $Z_S = Z'$ (equation 9) and $U_S = U_M$.

The initial amplitude of the oscillation is :

14) $$U_1 = U_M . \sin \phi$$

The maximum dv/dt is :

15) $$\frac{dv}{dt} = U_1 \frac{2\Pi}{T_o} = U_1 . \omega_o$$

(In this equation, the damping of the oscillation is neglected).

By replacing ω_o by equation 12, we have :

16) $$\frac{dv}{dt} = \frac{U_1}{\sqrt{L . C_S}}$$

17)
$$\frac{dv^2}{dt} = \frac{U_1^2}{L \cdot C_s}$$

18
$$\boxed{C_s = \frac{U_1^2}{L \dfrac{dv^2}{dt}}}$$

The peak voltage U_p of the oscillation can be max. $2U_1$, but the triac has its own limit which is its repetitive blocking voltage V_{DROM}. The voltage U_p must never exceed the triac's V_{DROM}. Two cases must be considered :

a)
$$U_1 \leqslant 0{,}5\ V_{DROM}$$

In this case the oscillation does not have to be damped, and R_s could be neglected. But the discharge current of the condenser C_s in the triac must be limited and we can assume :

$$R_s \geqslant 10\ \Omega$$

b)
$$U_1 > 0{,}5\ V_{DROM}$$

In this case, the amplitude of the oscillation must be limited so that :

19)
$$U_p = U_1 + U_2 \leqslant V_{DROM} \quad \text{(Fig.6b)}$$

The decrement of the oscillation is given by the equation :

20)
$$\frac{U_1}{U_2} = e^{\frac{\Theta}{2}}$$

21)
$$\Theta = \frac{\Pi}{Q}$$

22)
$$\frac{\Theta}{2} = \frac{\Pi}{2Q} = \ln \frac{U_1}{U_2} = 2{,}3 \log \frac{U_1}{U_2}$$

23)
$$\frac{1}{Q} = \frac{2 \cdot 2{,}3}{\Pi} \log \frac{U_1}{U_2} = 1{,}465 \log \frac{U_1}{U_2}$$

By combination of equations 13 and 23, we have

24) $$\frac{1}{Q} = 1{,}465 \log \frac{U_1}{U_2} = \frac{R + R_S}{\sqrt{\frac{L}{C_S}}}$$

25 $$\boxed{R_S = 1{,}465 \log \frac{U_1}{U_2} \sqrt{\frac{L}{C_S}} - R}$$

If the load is very inductive (power factor below 0,8) it is easier to assume R=0 and Z=ωl. For L we have:

26) $$L = \frac{U_{RMS}}{\omega I_{RMS}}$$

The values of the snubber network R_S-C_S are:

18) $$\boxed{C_S = \frac{U_1^2}{L(dv/dt)^2}}$$

25) $$\boxed{R_S = 1{,}465 \log \frac{U_1}{U_2} \sqrt{\frac{L}{C_S}} - R}$$

U_1 and U_2	in	V
R and R_S	in	Ω
L	in	H
C_S	in	F
dv/dt	in	V/s

Example 1

Main	: 220 V $\pm$ 10 %	f = 50c/s
Triac	: V_{DROM} = 500V	dv/dt = 4V/µs
Load	: Z = 22Ω	Power factor cosφ = 0,8

With these elements,

$U_M = 220.\sqrt{2}.1{,}1 = 342V$

$\omega = 2\Pi f = 10^2.\Pi$ rad/s

$\sin\phi = \sqrt{1-\cos^2\phi} = \sqrt{1-0{,}64} = 0{,}6$

$R = Z.\cos\phi = 22.0,8 = 17,6\ \Omega$

$\omega L = Z.\sin\phi = 22.0,6 = 13,2\ \Omega \qquad L = 0,442H$

14) $U_1 = U_M \sin\phi = 342.0,6 = 205V$

18) $$C_S = \frac{U_1^2}{L(dv/dt)^2} = \frac{205^2}{4,2.10^{-2}\ (4.10^6)^2} = 0,625.10^{-7} F$$

$$C_S = 68nF$$

As $U_1 = 205V < 0,5\ V_{DROM}$, it is not necessary to limit the amplitude of the oscillation, therefore :

$$R_S = 10\ \Omega$$

Example 2

Main : $220V \pm 10\ \%$ $\qquad f = 50c/s$

Triac : $V_{DROM} = 500V$ $\qquad dv/dt = 4V/\mu s$

Load : $Z = 22\Omega$ $\qquad \cos\phi = 0 \quad (R=0)$

$U_M = 342\ V \qquad \omega = 10^2\ \Pi\ rad/s \qquad \sin\phi = 1$

$\omega L = Z = 22\ \Omega \qquad L = 0,07H$

14) $U_1 = U_M.\sin\phi = 342.1 = 342V$

18) $$C_S = \frac{U_1^2}{L(dv/dt)^2} = \frac{342^2}{7.10^{-2}\ (4.10^6)^2} = 1,04.10^{-7}\ F$$

$$C_S = 0,1\mu F$$

19) $V_{DROM} = 500V = Up = U_1 + U_2$

$U_2 = 500 - 342 = 158V$

25) $$R_s = 1,465 \log \frac{U_1}{U_2} \sqrt{\frac{L}{C_s}} - R$$

$$= 1,465 \log \frac{342}{158} \sqrt{\frac{7.10^{-2}}{10^{-7}}} - 0$$

$$= 4,12.10^2$$

$$R_s = 470\ \Omega$$

Note :

The circuit can oscillate only if :

27) $$R + R_s < 2\sqrt{\frac{L}{C_s}}$$

The circuit is damped critically when

28) $$R + R_s = 2\sqrt{\frac{L}{C_s}}$$

Equation 25 gives us :

29) $$R + R_s = 1,465 \log \frac{U_1}{U_2} \sqrt{\frac{L}{C_s}}$$

30) $$1,465 \log \frac{U_1}{U_2} = 2$$

31) $$\boxed{\frac{U_1}{U_2} = 23.15}$$

We have 3 possibilities :

I) $\frac{U_1}{U_2} < 23{,}15$ the circuit oscillates

II) $\frac{U_1}{U_2} = 23{,}15$ the circuit does not oscillate

III) $\frac{U_1}{U_2} > 23{,}15$ the circuit does not oscillate

In the two last cases the voltage reapplied to the triac at turn-off does not exceed the voltage $U_1 = U_M \sin\phi$, and $U_2 = 0$. The contradiction appearing in cases II and III results from the fact that in equation 15, the damping of the oscillation has been neglected.

In practice, this means that the voltage will be reapplied to the triac at a lower rate than that allowed. Therefore, the dv/dt stress will be lower than expected.

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